A broader view on health care system design and modelling

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Abstract Many rigorous models have been developed to support health care system design. However, embedding these models in a broader stakeholder based framework, will substantially enhance the societal and human impact of the health care service delivery. Moreover, the acceptance of the (re)designed health care system will be much more evident for all stakeholders involved. These broader base of stakeholders will deliver a balanced set of Key Performance Indicators, against which the new design options or scenarios will be evaluated. These scenarios will be the outcome of an iterative design and modelling process moderated by a group of key stakeholders. Subsequently, a multi-criteria ranking method will reveal a shortlist of championing scenarios. Finally, a group decision process will decide on the final design choice. We build upon an exemplary model of a Nuclear Magnetic Resonance scanning department.

Keywords: health care system design, integrated design and model, stakeholder analysis, flow systems, scenario ranking, patient-centered design

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1 Introduction

The initial goal of a health care system, is not only to address the medical needs of individuals (e.g. patient versus physician) but also involves other factors affecting their own and the general well-being. An important underlying factor is patient satisfaction, which has been measured indirectly by capturing the patient experience (Bleich et al.2009). The three main goals of a health system, as considered by the World Health Organization (WHO) are: health improvement, responsiveness and fairness in financial contribution (Murray and Frenk2000, Musgrove et al.2000)

From a modelling point of view, health care systems have typically been approached by a limited selection of tangible performance dimensions such as technical capacity, waiting times, cost of care, among others (Brailsford et al.2004). Starting from the performance measures of a national health system, the goals for subsystems and individual organizations, e.g. hospitals, can be derived. This results in a set of performance indicators which encompasses the more diverse aspects of patient experience, health improvement and fairness of financial contribution. It is clear that some inherently conflicting goals need to be brought into balance, which is the reason why we propose an integrated approach for design and modelling of the health care system. The challenges faced by today's health care systems are twofold, either emerging from the demand side (the service receiving side) or from the supply side (the service delivering side). On the one side -the demand/receiving side- there are broader, more dynamic and advanced patient aims, which contribute to the service quality

(Haron et al.2012): the comfort of the patient, the exchange of information, the possibility of quick response and waiting times, the experience of patient rooms, the delivery and availability of drugs, the relation with the caregivers (nurses, physicians) and the role of information towards patient and relatives, and many more. On the other side -the system/supply side-, the use of health care resources experiences more and more the pressure of efficiency: government budgets, scarce skilled resources, logistics expenses, increased regulations, extremely expensive equipment, considerable environmental impact and production of hazardous outputs, etc. Also it became clear (Thakur et al.2012, Vandaele et al.2003) that the adoption of a newly designed health care system depends on the support it gets from the key stakeholders involved, e.g. the clinical staff. All of these contribute on top of the issues raised from the demand side, among others, to a very complex design problem (Beyan and Baykal2012).

Typically the modelling of a health care system has been directed in a bottom up way: adding more and more incremental improvements to the operational models under study (Rechel et al.2010, Taboada et al.2011). In this paper we look at the health care design problem in a more top down way: from a human-centred design point of view and not from a modelling point of view as a starting point for our analysis. Health care systems need to excel on both technical, economic, and a vast amount of human and social aspects. Due to the multitude of stakeholders involved, it is a challenge to identify improvements for an existing health care system or to design radically new health care systems leading to an overall better societal, economic and technical performance. A patient-centred design approach, instead of a disease-centred one, is expected to deliver such radical steps forward (Barry and Edgman-Levitan2012). Since there are a large amount of interconnected stakeholders in the health care system, and significant budgets involved, radical changes cannot be realised by a sole stakeholder on his own. A group-decision will precede the adoption of a new system.

Our research question materializes as: “How can the rigorous modeling efforts be encapsulated in order to ensure a deeper lived-through implementation that preserves the promising results?” In the next section we introduce a model of a Nuclear Magnetic Resonance (NMR) scanning unit as to illustrate the traditional modelling approach. Section 3 describes our suggested integrated stakeholder approach. Section 4 concludes the paper.

2 Healthcare system design from a “traditional viewpoint”

To illustrate the general idea of section 1, we build upon a real-life example from literature, which deals with an effort to improve patient waiting times for a NMR scanning department as part of a way to improve patient/customer service in general. More technical details and results can be found in (Vandaele et al.2003).

2.1 Initial flow model and results

The objective was to improve both patient waiting times (at the day of the scan) as well as patient backlog times (time between the date the appointment is made and the date of the scan). The hospital envisioned the patient lead time as primary key performance indicator for a sustainable customer service and thus preserving the long term success of the hospital. This objective was put forward without questioning the impact on and reaction of various stakeholders. Like in many (re)design projects, it turned out that the suggestions for operational improvements were valid but hardly implemented and suffered from resistance of particular stakeholders which were not involved in the (re)design exercise.

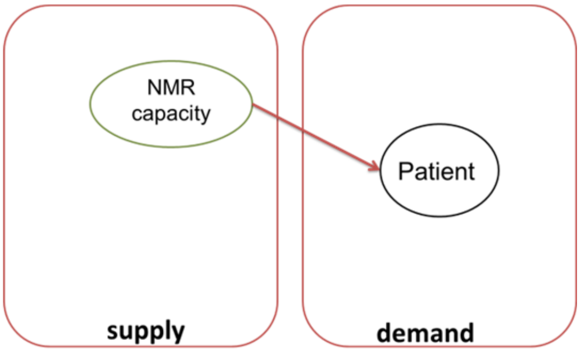

Fig. 1 The traditional modelling approach

Both the supply side and the demand side of the NMR scanner have been modelled as a multi-class, single-server open queueing model, as represented in Figure 1, where we use the following notation:

- k scan type index, $1, \ldots, K$
- $\overline{Y}_k$ average interarrival time of scan type k
- s^2_{Yk} interarrival time variance of scan type k
- c^2_{Yk} squared coefficient of variation of the interarrival time of scan type k
- $\lambda_k = 1/\overline{Y}_k$ average arrival rate of scan type k
- $\overline{T}_k$ average setup time for scan type k
- s^2_{Tk} setup time variance for scan type k
- c^2_{Tk} squared coefficient of variation of the setup time of scan type k
- $\overline{X}_k$ average unit processing time of scan type k
- s^2_{Xk} unit processing time variance for scan type k

- c^2_{Xk} squared coefficient of the unit processing time of scan type k
- $\mu_k = 1/\,\overline{X}_k$ unit processing rate of scan type k

In the model, the parameters of the individual arrival and service processes are combined with the group size decision and are subsequently aggregated into a single aggregate arrival and service process respectively. Note that the setup time is needed for mainly calibration while the process time includes the preparation time (moving in and covering parts of the body), the scanning time (taking measurements and performing calculations) and the post-operation time (removing the patient and cleaning).

The aggregate arrival process

Assuming a scanning group size of Q_k (≥ 1), the average group arrival rate of scan type k is given by l_k:

$$l_k = \frac{\lambda_k}{Q_k}. \qquad (1)$$

The aggregate group arrival rate at the NMR scanner can be obtained:

$$l = \sum_{k=1}^{K} l_k. \qquad (2)$$

The squared coefficient of variation of the group interarrival time for scan type k can be calculated as follows:

$$ca_k^2 = \frac{c_{Yk}^2}{Q_k}. \qquad (3)$$

The squared coefficient of variation of the aggregate group interarrival time at the NMR scanner is approximated by

$$ca^2 \approx \frac{1}{3} + \frac{2}{3}\left(\sum_{k=1}^{K} \frac{l_k}{l} ca_k^2\right) \qquad \textit{for } K > 1. \qquad (4)$$

Further details on this approximation can be found in (Lambrecht and Vandaele1996) and (Vandaele1996).

The aggregate group service process

The average aggregate group processing time is calculated as a weighted average of the individual group processing times:

$$\frac{1}{\mu} = \sum_{k=1}^{K} \frac{l_k}{l}\left[\overline{T}_k + Q_k \overline{X}_k\right]. \qquad (5)$$

The weights reflect the relative importance of the group arrivals of the different scan types.

The squared coefficient of the aggregate group processing times is approximated by:

$$cs^2 = \left[\left(\sum_{k=1}^{K} \frac{l_k}{l}\left[\overline{T}_k + Q_k \overline{X}_k\right]^2\right)\mu^2 - 1 \right] + \left[\sum_{k=1}^{K} \frac{l_k}{l} \frac{\left[s_{Tk}^2 + Q_k s_{Xk}^2\right]}{\left[\overline{T}_k + Q_k \overline{X}_k\right]^2} \right]. \qquad (6)$$

Two variability effects can be observed: the first term of the equation reflects the differences in average group processing times among the scan types. As such, it can be seen as a measure of *heterogeneity between the scan types*: if all average setup and processing times are equal (meaning that $\overline{T_k} = \overline{T}$ and $\overline{X_k} = \overline{X}, \forall k$) , the first part becomes zero. Further details on the derivation can be found in (Lambrecht and Vandaele1996).

The second term is a weighted average of the squared coefficients of variation of the individual group processing times. As such, it can be seen as a measure of the *variability inherent in the processing times of the individual scan types*. If all setup and processing times are deterministic, this sum equals zero. Note that all aggregate arrival and processing characteristics are functions of the group size Q_k.

Given the aggregate arrival rate l and the aggregate processing rate μ, the effective traffic intensity ρ_e can now be calculated. It measures the workload of the NMR scanner for a given capacity, and is the traditional traffic intensity ρ increased by the additional load effect from the setup times [5]:

$$\rho_e = \frac{l}{\mu} = \sum_{k=1}^{K} l_k \left[\overline{T}_k + Q_k \overline{X}_k \right] = \sum_{k=1}^{K} l_k \overline{T}_k + \rho \tag{7}$$

where ρ is defined as

$$\rho = \sum_{k=1}^{K} \rho_k = \sum_{k=1}^{K} \frac{\lambda_k}{\mu_k} . \tag{8}$$

From equation (7) it is clear that the effective traffic intensity is dependent on the group sizes Q_k. For large group sizes, l_k tends to zero, and ρ_e approaches the traditional traffic intensity ρ. For small group sizes, ρ_e increases due to the impact of the setup times. The increased traffic intensity causes congestion and therefore, ρ_e should be strictly smaller than unity which implies that there is a lower bound on the group sizes.

Objective function and optimization

Given the average group arrival rate λ_k and average group processing rate μ_k, the expected lead time for each scan type k can be obtained:

$$E(W)_k = \frac{Q_k - 1}{2\lambda_k} + E(W_q) + \overline{T}_k + \frac{Q_k + 1}{2\mu_k} . \tag{9}$$

This lead time clearly consists of four building blocks. The first term corresponds to the average time a patient of scan type k will have to wait until a group of size Q_k has been formed (*collection time*). The term $E(W_q)$ stands for the average time that patients spend waiting in queue in front of the scanner until it becomes idle (*waiting time*). The last two terms correspond to the average time a patient of scan type k spends in setup and processing. The model assumes a FIFO-discipline, which is accepted to be fair among patients in a waiting room.

The expected waiting time $E(W_q)$ is approximated by the Kraemer-Lagenbach Belz formula (for the original publication see (Kraemer and Langenbach-Belz1976); the approximation is also discussed in (Suri and Kamath1993), and is independent of the scan type:

$$E(W_q) = \frac{\rho_e{}^2\left(ca^2 + cs^2\right)}{2l\left(1-\rho_e\right)} \exp\left\{\frac{-2\left(1-\rho_e\right)\left(1-ca^2\right)^2}{3\rho_e\left(ca^2+cs^2\right)}\right\} \qquad (10)$$

$$if \quad ca^2 \leq 1$$

$$E(W_q) = \frac{\rho_e{}^2\left(ca^2 + cs^2\right)}{2l\left(1-\rho_e\right)}$$

$$if \quad ca^2 \geq 1$$

Finally, the aggregate average lead time $E(W)$ is calculated as a weighted average of the lead times of all individual scan types:

$$E(W) = E(W_q) + \sum_{k=1}^{K} \frac{\lambda_k}{\sum_{k=1}^{K}\lambda_k}\left[\frac{Q_k - 1}{2\lambda_k} + \overline{T}_k + \frac{Q_k + 1}{2\mu_k}\right]. \qquad (11)$$

The weights reflect the relative importance of each scan type for the NMR scanner. Here, the importance is measured by means of the volume per scan type.

The optimization problem can now formally be stated as follows:

Min

$$E(W) = E(W_q) + \sum_{k=1}^{K} \frac{\lambda_k}{\sum_{k=1}^{K}\lambda_k}\left[\frac{Q_k - 1}{2\lambda_k} + \overline{T}_k + \frac{Q_k + 1}{2\mu_k}\right]$$

s.t. $\rho_e < 1$

$Q_k \geq 1$

Based on experimental evidence, the convexity of *E(W)* in the vector of patient group sizes ***Q*** can be postulated (see also (Vandaele1996)), for the convex domain described by the intersection of the constraints. This non-linear constrained optimization problem is solved using a dedicated optimization algorithm: the problem is treated as an unconstrained optimization problem which is solved in a numerical way by a descent method, while at each iteration the constraints on the patient group sizes Q_k and the traffic intensity ρ_e are guaranteed to be satisfied. The outcome of this algorithm then yields the optimal group size Q_k^* for each scan type *k* (Lambrecht and Vandaele1996, Vandaele1996).

The expected individual lead time for a patient of scan type *k* can then be obtained by entering Q_k^* into Equation (9):

$$E(W)_{k\,OPT} = \frac{Q_k^* - 1}{2\lambda_k} + E(W_q)(Q_k^*) + \overline{T}_k + \frac{Q_k^* + 1}{2\mu_k} \qquad (12)$$

The variance of this optimal individual lead time is given by (Lambrecht and Vandaele1996, Whitt1983):

$$V(W)_k = \frac{Q_k^* - 1}{2} s_{Yk}^2 + \frac{(Q_k^* - 1)(Q_k^* + 1)}{12\lambda_k^2} + V(W_q) + s_{Tk}^2 + \frac{Q_k^* + 1}{2} s_{Xk}^2 \qquad (13)$$

$$+ \frac{(Q_k^* + 1)(Q_k^* - 1)}{12\mu_k^2} - \frac{(Q_k^* - 1)(Q_k^* + 1)}{6\lambda_k \mu_k}$$

In this formula, $V(W_q)$ stands for the variance of the waiting time spent in queue and is not dependent on the product type. The approximation is based on Whitt (Whitt1983), of which further details can be found in (Vandaele1996).

Assuming a lognormal distribution for the individual patient lead times, the values of $E(W)_k$ and $V(W)_k$ enable us to calculate the minimal lead time W_{Pk} that the hospital has to quote to the patients in order to guarantee a certain customer service level P_k (as the the percentage of time that patients of type k are served within the quoted lead time). Given a customer service level P_k, it can be derived from the lognormal distribution that:

$$\ln(W_{Pk}) = \beta_k + z_{Pk}\gamma$$

with

$$\beta_k = \ln\left(\frac{E(W)_k}{\sqrt{\dfrac{V(W)_k}{E(W)_k{}^2} + 1}}\right)$$

$$\gamma_k^2 = \ln(\frac{V(W_k)}{E(W_k)^2} + 1)$$

and where z_{Pk} is the standard normal variable yielding a cumulative percentage P_k. Consequently, the quoted lead time W_{Pk} equals:

$$W_{Pk} = \exp\{\beta_k + z_{Pk}\gamma_k\}$$

This quoted lead time concept can be used to obtain an approximation for the backlog of the NMR scanning department and also to suggest at what time the patients should be in the department prior to their appointment on the day of the appointment in order to safeguard the scanning schedule.

Result from the NMR example

From Fig. 2 it can be understood that the demand side consists of a patient flow represented by six scan classes. The supply side is modelled by a multi-class, single station queueing system. The flow originates from both recommendations from physicians as well as from patient's own initiatives. Each class represents a family of scans with similar technological characteristics as shown in Table 1:

Scan type	Description	Abbreviation
1	Skull/Foot/Ankle	SFA
2	Lumbal spine	LS
3	Cervical spine	CS
4	Shoulder/Hip	SH
5	Knee/Wrist/Elbow	KWE
6	Rest (neck, breast, etc.)	REST

Table 1: The six scan types

Related to the supply side, per class, several individual scans are grouped to form a batch for which a general setup is performed after which each patient undergoes his scan.

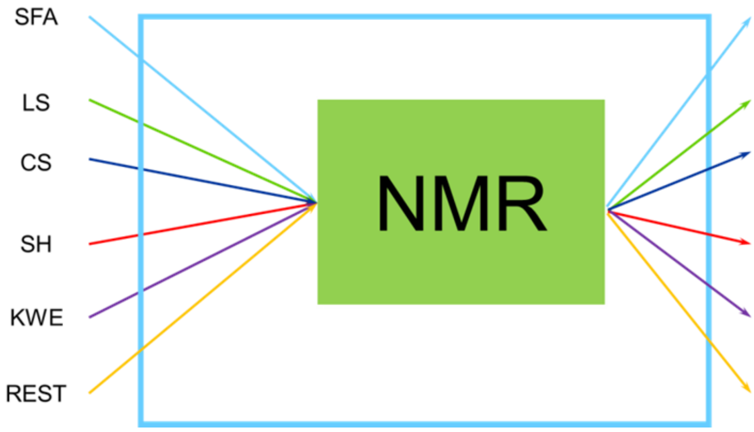

Fig. 2 The flow model of the NMR department

The overall objective was to minimize the aggregate weighted lead time over all classes as a function of the six scan group sizes. Field data were collected to obtain first and second moments of the arrival, setup and process times. A summary of the modelling details can be seen in Fig. 3.

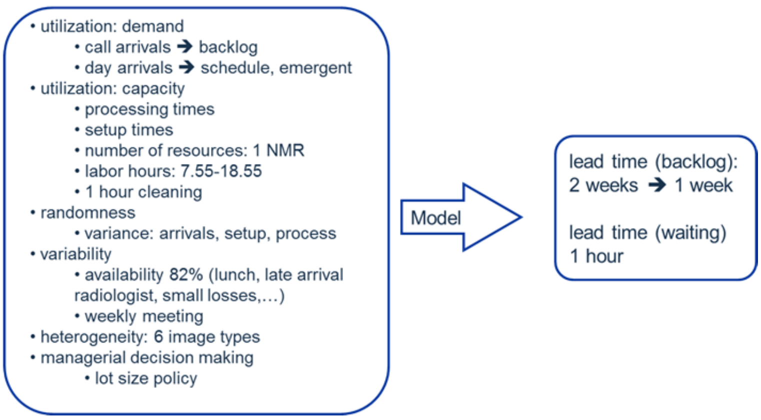

Fig. 3 The flow model details of the NMR department

In summary, the outcome was that the by taking proper measurements and appropriate managerial decision making in terms of batch sizing, the patient backlog could be reduced from two weeks to one week and that the waiting times on the day of the scan was about one hour.

The details are shown in Table 2.

Scan Type	Backlog (days)		Waiting time (minutes)	
	Old	New	Old	New
SFA	9.55	4.09	50.67	25.84
LS	6.33	3.54	35.7	18.21
CS	7.28	4.08	39.75	20.27
SH	9.65	4.58	57.2	29.17
KWE	7.21	3.50	36.69	18.71
REST	8.67	4.42	47	23.97

Table 2: The operational improvements in patient backlog and waiting time on the day of the scan

Although quite promising, the suggested improvements were not implemented, the question remains: why? Clearly, this queueing model did not take into account the various stakeholder issues which made a proper implementation difficult. Especially the clinicians' viewpoint is definitely not embedded in the model. This will be discussed in the next subsections. A final remark relates to the fact that the queueing approach can be replaced by any predicting (forward) flow modelling approach (Armbruster D.2012) . In the literature, simulation and systems dynamics are popular alternatives (Brailsford et al.2004).

3 Healthcare system design from a "stakeholders' viewpoint"

The main lessons learned from the narrowly modelled new healthcare system were twofold: the adoption of the newly designed system was prevented because important stakeholders, in this case the clinicians, were not involved and did not accept the new system as such. Secondly, the system performance was exclusively measured on technical and operational parameters, even concentrated on optimizing lead time and backlog only. Hereby, the human related factors of the healthcare system were strongly neglected. It is clear that any healthcare system, from its intrinsic purpose, has a fundamental human goal of creating sustainable wellbeing for people (Musgrove et al.2000). If the new system as described in the previous section would have been implemented, it would have been an improvement also on human aspects for the patients and other stakeholders: the relatives of the patients, clinicians etc. To enable system designers and modellers to take into account these important aspects, we propose a five-step integrated design and modelling process starting from the stakeholders as shown in Fig. 4.

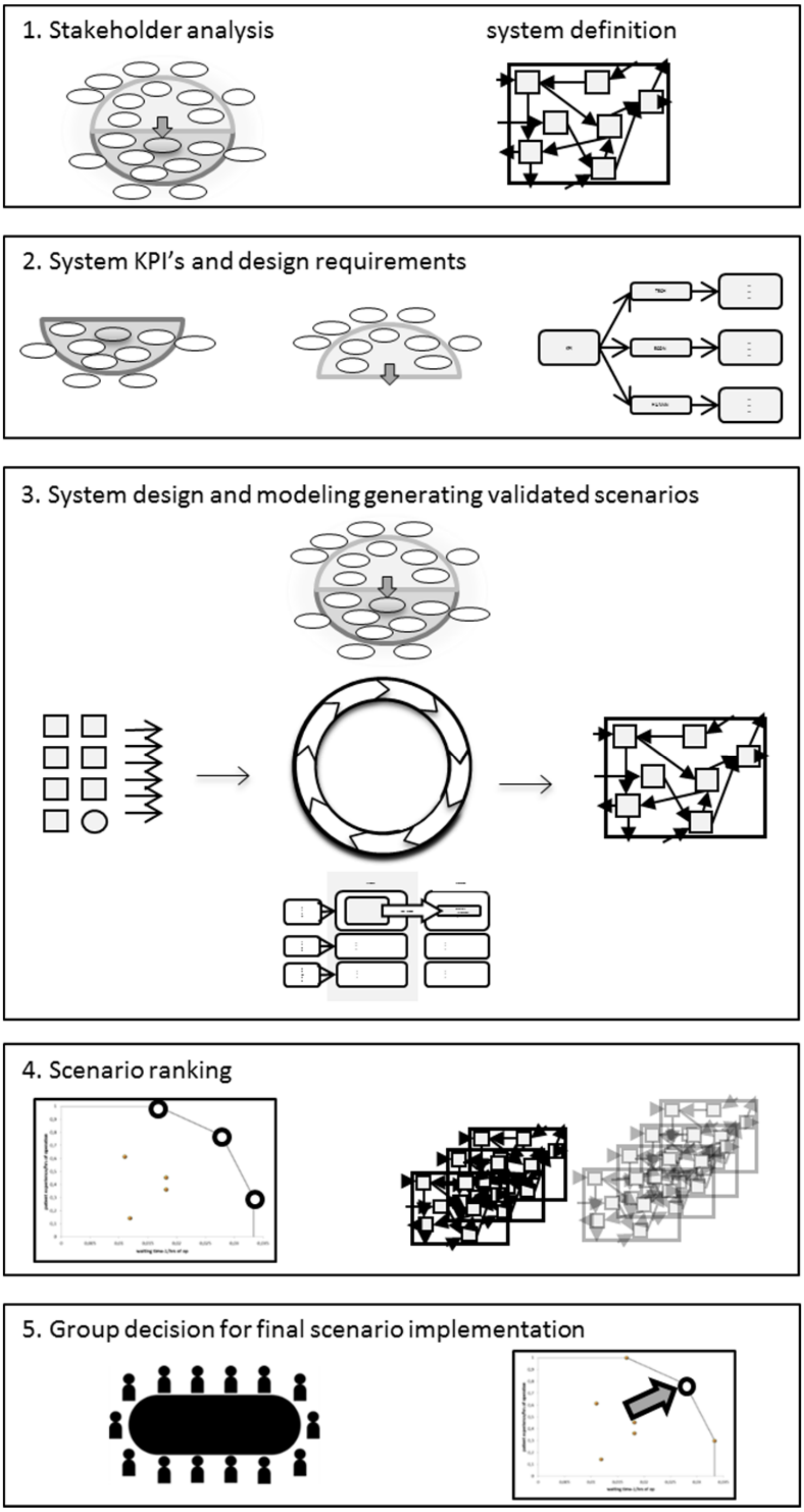

Fig. 4 Integrated health care system design and modelling process

3.1 Step 1: Stakeholder analysis and system definition

The starting point of the system definition is the articulation of the system goal: "what is the core service the system should deliver and for whom?" On the scale of an organization, this can be found in the organization's vision and mission statement. In the case of our example, the NMR department in a hospital, the system goal is: the provision of diagnostic information to the physician and to the patient. Once this goal is known, the next step is to identify the stakeholders involved and to define the system boundaries and elements (see section 2).

The stakeholder concept has been defined in numerous ways since it was originally developed in the context of corporate strategy and for instance defined by Freeman (Freeman2010) as follows: "*any group or individual who can affect or is affected by the achievement of the organization's objectives".* It is equally applicable to a health care system which is spread over single or multiple entities. Different stakeholders have a specific relationship to the organization and may lead to conflicting interests. Stakeholder theory (Mitchell et al.1997) proposes a typology and suggests ways of working with the different types based on legitimacy, power and urgency. For applications in the field of R&D project management (Elias et al.2002) and system design, specific stakeholder attributes such as interaction mode (functional, financial, decision power) (Donaldson et al.2006) and stakeholder dynamics are of great value (Solaimani et al.2013).

For the purpose of system design, we make the distinction between two groups of stakeholders: internal and external stakeholders. Internal stakeholders are those people, roles or organizations directly or indirectly impacting and impacted by the delivery or the reception of the service. Internal stakeholders are part of the system (either demand or supply) and they will be actively involved in the design and the decision process of the new system (see steps 3 and 5). Stakeholders belonging to the environment of the system and not to the system itself, referred to as external stakeholders, will have a direct or indirect impact on the performance of the system, but are not impacted by the system themselves. These stakeholders often play an important role in the design options for the new system and cannot be controlled by the system itself. They can however be influenced by other stakeholders or by the system once it is operational. Examples of external stakeholders are sources of information which influence the expectation of the patient (e.g. public online databases or testimonials from other patients) or regulatory bodies putting technical restrictions to system design or governmental funding authorities determining part of the budget should therefore be taken into account during the design and decision process. A stakeholder mapping for the NMR example from chapter 2, is shown in Fig. 5.

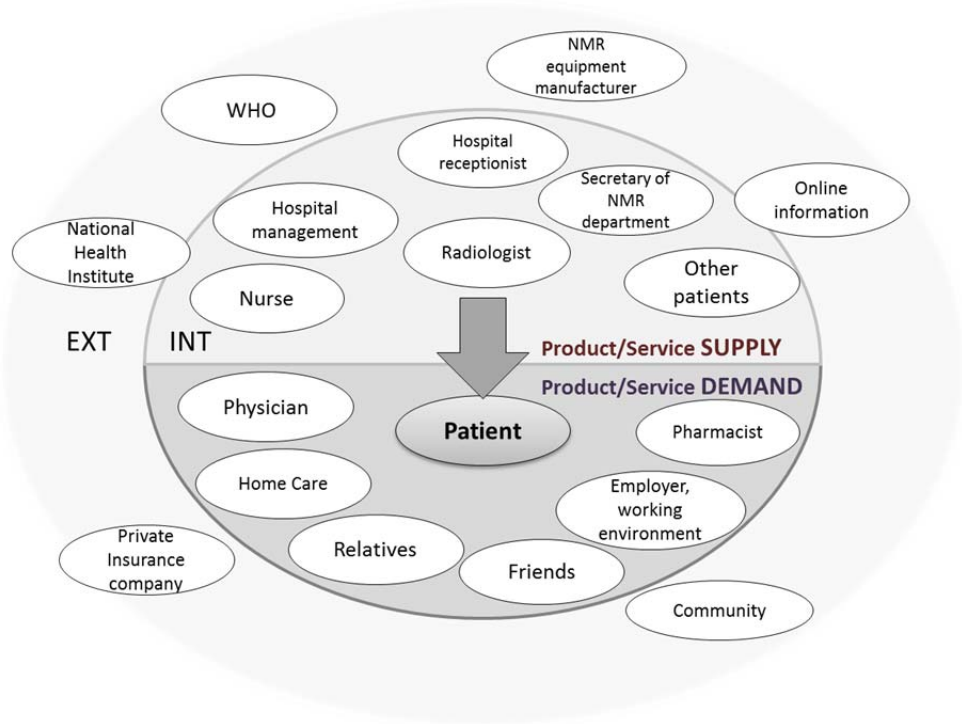

Fig. 5 Stakeholder mapping from a patient-centred perspective

Positive results of stakeholder mapping workshops in healthcare systems design were shown earlier and stakeholder diagrams proved to be well understood by health care professionals (Buckle et al.2010, Buckle et al.2006, Jun et al.2009). As the supply side of the system can be quite complex, some stakeholders appear as a network representing their strategic partnerships and common goals. Specifically for health care, the transition of care and information from one supplier or one service system to another is a critical element for the overall service performance (Ross et al.2013). Also on the service demand side, different stakeholders can be linked and networked. Examples are the patient and his family, the family and the home care organization, etc. For each of the stakeholders, the nature of interaction during the NMR scanning process is determined: experience interaction, financial interaction or decision making influence, as shown in Fig. 6 for the case of the NMR service system.

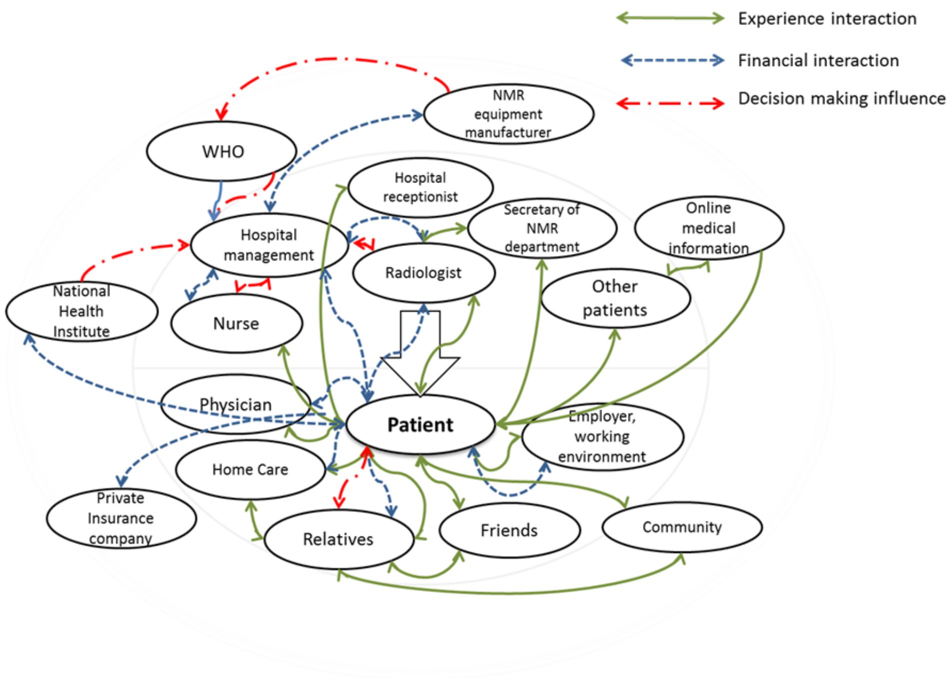

Fig. 6 The stakeholder interaction diagram for the NMR design problem

Some of the stakeholders will be directly involved in the actual services delivered by the system, they will be either participating in the delivery or the reception of a service. This type of interaction is for the purpose of this paper named experience interaction, and it covers all three levels of interaction: the functional level, the usability level and the emotional level (Norman2007). The needs of these stakeholders and the experienced performance of the new system designs, deliver the core information for human centred system design. These stakeholders involve the patients and their families, clinicians and nurses. Other stakeholders will have a financial interaction with the system and do not necessarily take part in the health care service itself. They set restrictions to the system design in terms of investments and cost of operation e.g. the insurance companies or social security bodies in general. A third kind of stakeholder are those with a strong decision power on the system design in terms of approving or rejecting a certain solution by the use of laws, rules or standards. They act as gatekeepers or constraints for the system design and their aim can be the controlled acceptance of new technology with respect to ethics or safety. The national health security organization and WHO are examples of these. Stakeholders can interact on several levels at the same time, e.g. a patient interacts both on the functional as well as on the financial level, but usually not on the decision level.

The system to be designed will be a part of a larger health care ecosystem. The definition of the system and its boundaries starts not from an existing health care department which should be improved, but must find its origin in the needs of the patients at the service receiving side and in the contribution and goals of the stakeholders at the service delivery side. The physical system capable of delivering the service will be the result of that, this is in contrast to the traditional modelling described in chapter 2. In our NMR example described earlier the system was defined only by the existing boundaries of the NMR unit, its staffing, skills and actual patient types at the specific hospital. On the other hand the health care system will be designed based on the future diagnostic needs of the patients and the goals of the health care providing and receiving stakeholders. When a patient-centred perspective is taken, the system is a fragment in a broader health care lifecycle in which a patient walks through different stages and where a multitude of stakeholders are found each time the patients visits the system. The system requirements will include aspects derived from the previous experiences by the patient, such as continuity and information availability. Therefore, the system elements and the boundaries of the healthcare system have to be defined by the specific type of health care needed for a chosen type of patient within the real boundaries set by the stakeholders. The boundaries will determine the flow, i.e. the kind and the number of patients in the system, the process steps taking place between a patient entering and leaving the specific system and the resources available to support the processes.

3.2 Step 2: System KPI's and design requirements

In this process step, the design research can be carried out. It will involve a mix of qualitative research methods such as patient observations and interviews, in order to gain empathy with the patients and other stakeholders involved. The resulting insights deliver information complimentary to the technical data from the process.

In product design, a human-centred approach usually starts from the user needs, usually the end-user, and takes a selection of other stakeholders into account. The user is preferably actively involved from the earliest stages in the design process, the idea generation phase throughout the concept definition and product development, for concept testing and prototype validation (Martin and Barnett2012). When designing a complex product/service system such as a health care system, a lot of different stakeholders' needs must to be taken into account simultaneously and conflicting requirements need to be solved in the new service design (Clarkson et al.2004). Stakeholder theory, and the principle of stakeholder salience, enable an organization to focus on the most important stakeholder. We propose an alternative to this approach and will not set an upfront priority to individual stakeholders. Instead, the requirements of all relevant stakeholders are taken as directions for the system design, and the resulting system scenario will be tested by the stakeholders and improved accordingly. This mechanism will be explained in step 3.

As it is reflected in some of the WHO's common set of domains (Murray and Frenk2000), such as "choice of care provider" and "respect for autonomy", the patient's decision power is expected to become more important in future health care systems. On the system performance, the patient experience is a main goal (Haron et al.2012, Parasuraman et al.1988) as it is a driver behind most of the KPI's for improvement of health and responsiveness of the system.

As far as the KPI's from the demand side are concerned, the result of the user research will reveal the patient needs and stakeholder insights to induce a holistic system design.

On the other hand, from the supply side the hospital declares its mission statement and institutional values, the hospital strives for the highest quality treatment and care. Its central values are patient kindness and safety. The engagement towards the patient comes down to enhancing the patient's quality of life on both physical and psychological level, taking into account the uniqueness of each patient. Furthermore, the hospital values the interaction with the supporting environment of the patient, i.e. his family and other caregivers. Logically, these elements are fully in line with the WHO's common health care system goals, but furthermore, they inspire the organization in its daily operations.

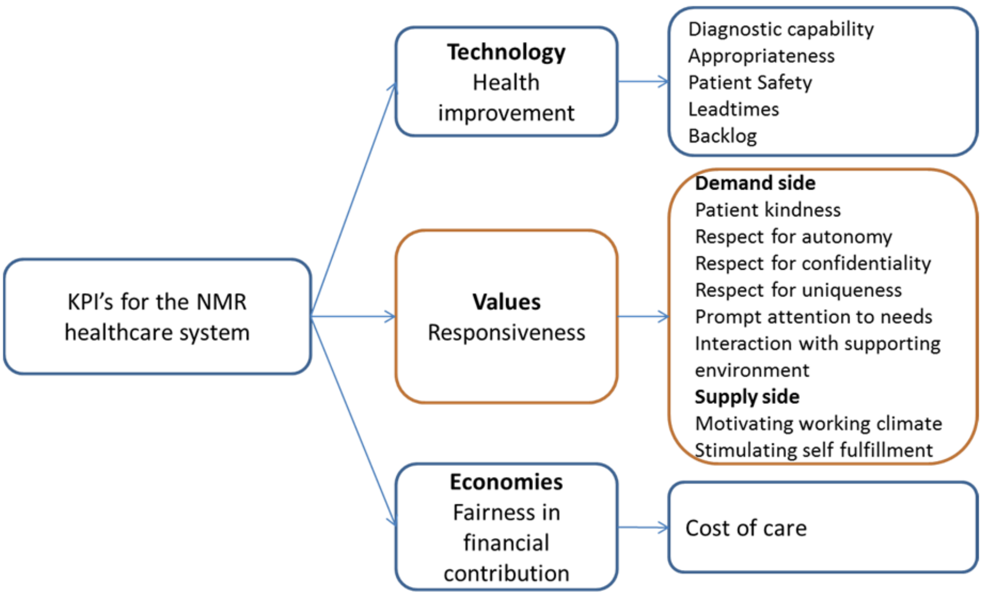

Fig. 7 The multi-dimensional KPI's of the NMR design problem

The engagement from the hospital towards its employees, including clinicians, focuses on creating a motivating working climate with room for self-fulfilment.

The analysis of these means and beliefs as stated by the hospital, leads to a set of high level aggregate KPI’s for system innovation, such as the redesign of the NMR process, as depicted in Fig. 7**.** This figure is an adapted version of a methodology developed for R&D portfolio management (Vandaele and Decouttere2013).

Individual stakeholders’ needs from people within the hospital are collected by observations, interviews or workshops as part of the user activities leading to the stakeholder insights. Although these needs are often qualitative, the intention is to measure them, even if it is hard and imperfect.

3.3 Step 3: System design and scenario building

The design process should actively involve the stakeholders from the demand side and the supply side, and is based on design thinking and participatory design (Brown et al.2008) (Rouck et al.2008). Stakeholders with experience interaction will be invited to take part in the system design. Their current experience in an existing NMR service system will inspire system designers to develop solutions for unmet needs.

Stakeholder	*Unmet need*	*Design solution*	*System attributes*
Patient	Reduce delay between call and day of visit to NMR	Online information on waiting times for different NMR services in network(*) Dedicated NMR departments Dynamic planning process New lot sizing policy	IT infrastructure Collaboration between NMR units Investments in infrastructure Specialized skills

	Perceived continuity between different NMR scans	Personalized contact building on previous scans and patient context Patient-centered processes Information sharing with patient Information flow between team members	Time for contact with patients Time for information sharing IT tools for information sharing Dedicated team members
Radiologist	Learning and self-fulfillment in service provided	Keep track of patient evolution and role of diagnostic part in it Get feedback from patients and physicians	Information flow between departments and institutes
Nurse	Self-fulfillment from working with patients	Patient-centred processes Capacity to decide in function of patient needs	Time dedicated with patients Dedicated team members

Fig. 8 Stakeholders' insights and derived system concepts

New system concepts created in this way can be radically different from the existing situation, and new technologies or new ways of working can be introduced. Examples of this in the NMR case are shown in Fig. 8, where the lot sizing policy leading to a shorter back log and a lower patient lead time is embedded in a much broader context. The different elements of a system are created and combined until a working concept results. Concept development methodologies from engineering design and product design, for example Quality Function Deployment (QFD) and Vision in Product Design (ViP), can be applied in this stage (Akao1990, Hekkert and van Dijk2011). The concept is iteratively modelled, optimized and tested with stakeholders, including mathematical modelling where possible. A working system concept, a prototype for a system is here referred to as a *scenario*. Scenarios can take various forms depending on the iteration cycle en development phase. Initially, the system design could be tested by a combination of simulation, mathematical analysis and even techniques like a role play based on a written prototype with allows for simulating the amount of time, infrastructure and human resources needed to check whether it can work in real life. With the involvement of real stakeholders, feedback on the system concepts is obtained and adjustments are made until the stakeholders validate it or rejected it. The validation by of a concept by the stakeholders literally means that the resulting scenario is capable of delivering the anticipated outcomes, by making use of the inputs foreseen in the scenario.When we go down the road to the modelling effort behind the (re)design of the system, we end up with rigorous modelling from Fig. 3, but now fully embedded in the multi-dimensional design approach as depicted in Fig. 7. The integration in terms of KPI’s is visualized in Fig. 10. The KPI’s for the design problem will be related to stakeholder’s needs and will generate ideas for improved or new NMR systems.

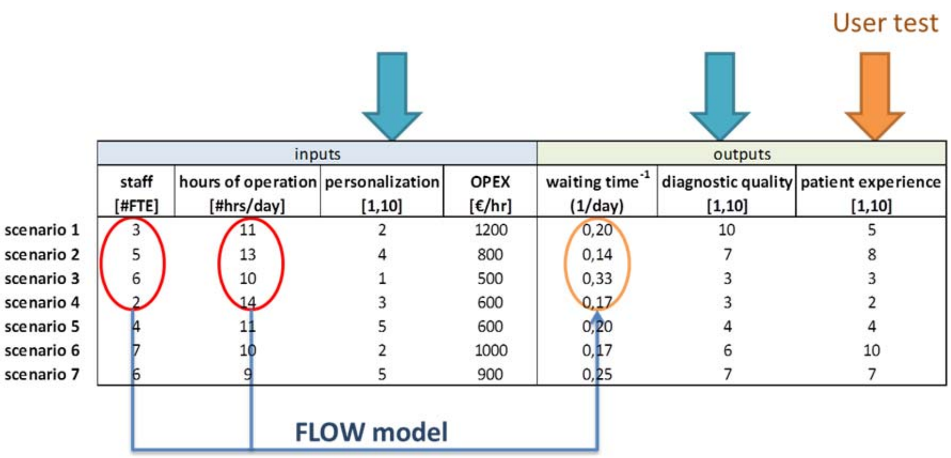

Fig. 9 Integration of mathematical model and user validation

On the three main dimensions of KPI’s, each system concept is represented by a set of inputs, limited resources, and outputs, desired outcomes. The flow model calculates the relation between a subset of inputs and outputs from the technology-pillar. The other inputs and output variables are the result of design activities. Many of the human-related outputs will be measured by qualitative techniques from user research and concept testing. Note that even the original flow model's objective of minimizing aggregate lead time is only one aspect, part of the technical main goal of improving health. Also the NMR equipment described by capacity, utilization and availability, is a myopic and limited view of the NMR supply side and part of the health improvement main goal.

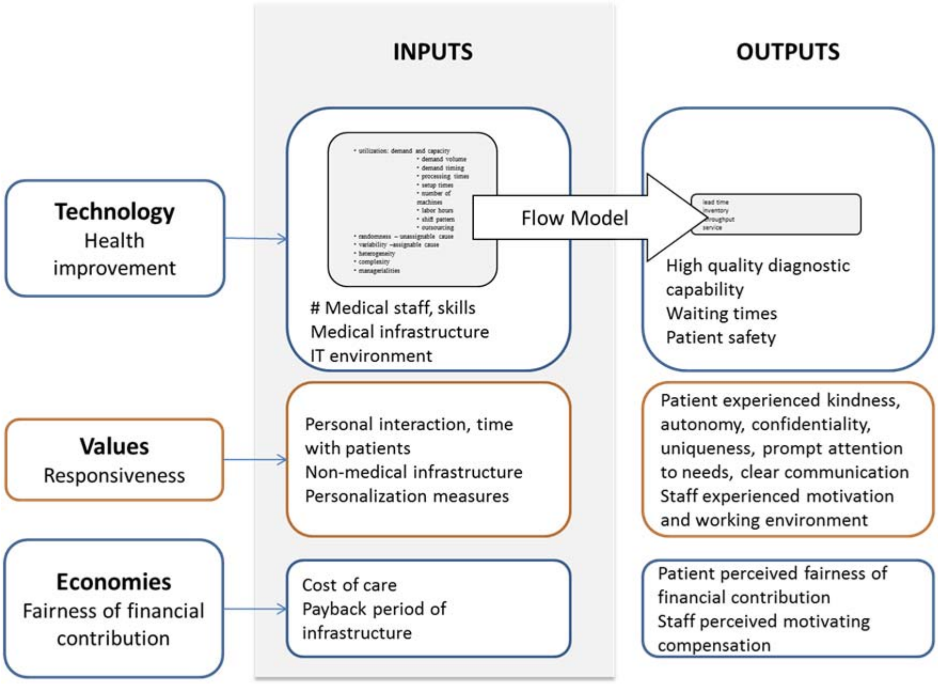

Fig. 10 The integrated NMR design problem

At this point we can expose a schematic overview of the broader health care system design and modelling process in Fig. 12, fully in line with Fig. 4. The start is the current health care system were user and stakeholders insights and possibly new technology, offer opportunities for improvement along the diverse KPI's. The decision making stakeholders put the limits to the solution space. The development of new system concepts is followed by testing with the stakeholders with experience and financial interaction, in short iterative cycles, each time improving the concept. The technological modelling is used as partial knowledge to model input and output characteristics of the health care system concepts. The iterative design/model process step continues until a satisfying validated system is reached, called a scenario. Each scenario is characterized by its set of input and output variables. A number of scenarios are constructed, possibly very diverse in the solution they offer to the design problem. We argue that any scenario building methodology can be useful here (see for instance (Brailsford2008) for a nice example).

3.4 Step 4: Scenario ranking

As a scenario will unlikely be championing on all dimensions from the diverse set of KPI's, we expect a couple of scenarios to be top of class and thus candidates for implementation. At this point, a multi-criteria ranking method brings great value to give insight into the multiple dimensions of the decision problem (Vandaele and Decouttere2013).

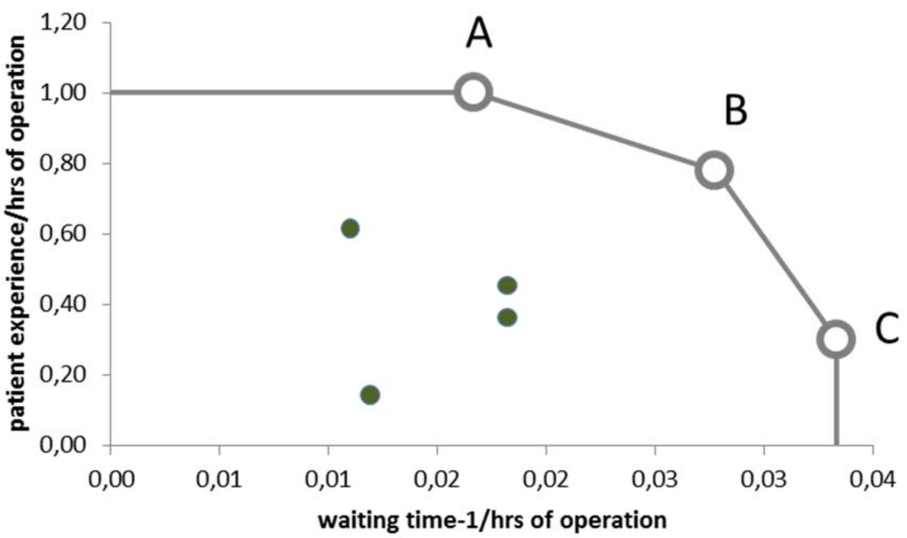

Fig. 11 Multi-criteria scenario evaluation

Since no prior importance was attributed by means of stakeholder salience, the diverse scenarios reflect different approaches leading to solutions accepted by the stakeholders. The best solutions are the ones on the efficient frontier in a relative assessment. A partial 2D view is shown in Fig. 11, where every dot represents a scenario and A, B and C are top ranked scenarios. Scenarios not on the frontier will not be optimal when compared on all dimensions simultaneously. In this way a shortlist of ‘best’ scenarios is handed over to the next step. In order to conduct this ranking step it is necessary to quantify the measurements on all KPI’s, even the more intangible ones (Vandaele and Decouttere2013).

3.5 Step 5: Group decision for final scenario implementation

With the help of effective visualisation techniques, such as infographics, insight is gained into the specific profiles of the top ranked scenarios. Each scenario can be considered as equally beneficial with respect to the set of health care system goals defined and for the stakeholders identified in the earliest stage of the process (step 1). In the knowledge that each of the scenarios are safe options which are accepted by the stakeholders, the decision group’s attention goes to selecting the best suited scenario in line with the organisation’s values and strategic goals, while fulfilling the short term objectives. The transparency of the scenario strengths according to these goals and the early involvement of the decision group in the proces, creates openness to consider the different solutions and avoids emotional caveats connected to risk taking, uncertainties and innovating. These create a right environment for overall better decision making in selecting the final scenario to be implemented (Kahneman and Tversky1979, Milkman et al.2009).

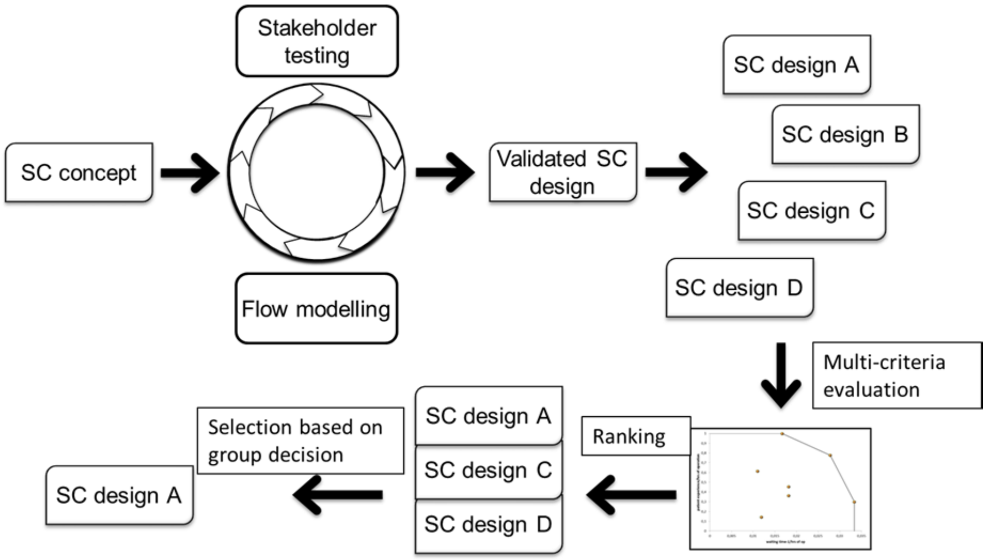

Fig. 12 The integrated health care design overview

4 Conclusions

In this paper we revisited the (re)design of an NMR service system. The after-project experience showed a very weak willingness to implement the model based promising suggestions for improvement. A major reason was the ignorant exclusion of major stakeholders in the design process, clinicians among others. Therefore a broader approach is put forward based on stakeholder analysis and user-centred design. Based on this analysis, more mind expanding and out-of-the-box design propositions can be generated which will then be dealt with by a multi-criteria decision method in order to select a set of 'best' design options, called scenarios. Additionally, the early involvement of key stakeholders in the design process can lead to scenarios with a much better fit and induce a higher willingness to implement the new health care service system. In this way we believe that health care system design will have a much higher probability of reaching the full-fledged implementation benefits for all stakeholders involved.

Future research encompasses a more detailed formalization of the proposed approach and the application of the methodology to other health care system design problems.

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